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Multiphysics Simulations of the Complex 3D Geometry of the High Flux Isotope Reactor (HFIR) Fuel Elements Using COMSOL

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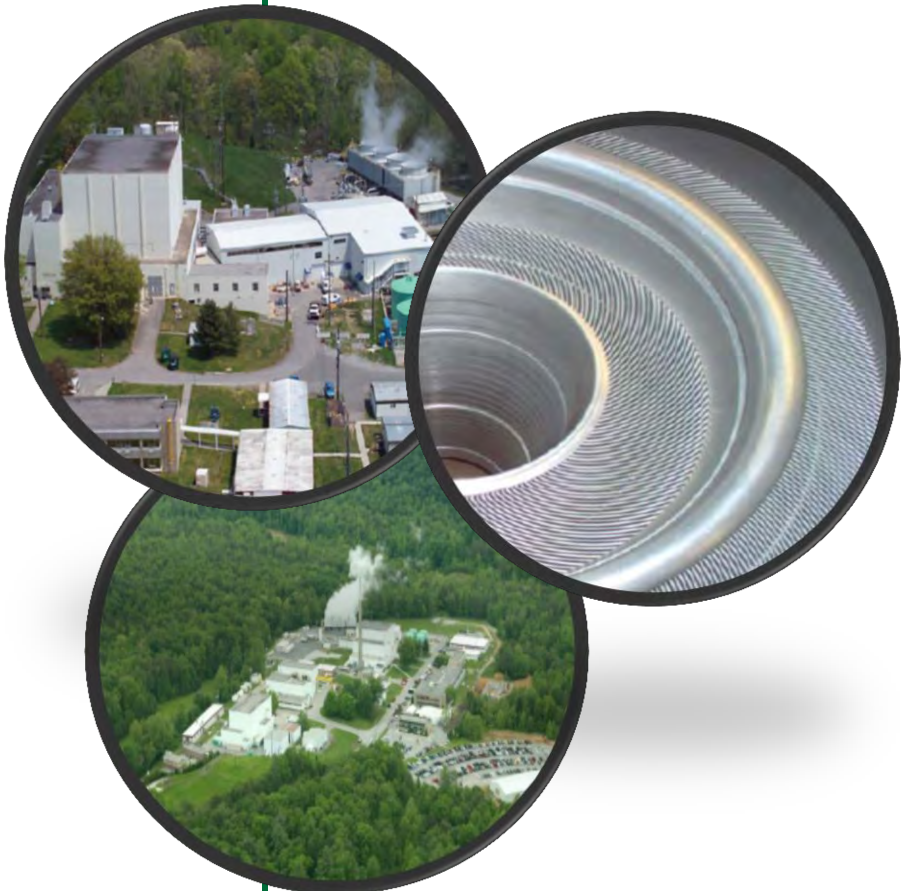

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October 14, 2011

OAK RIDGE NATIONAL LABORATORY

HFIR

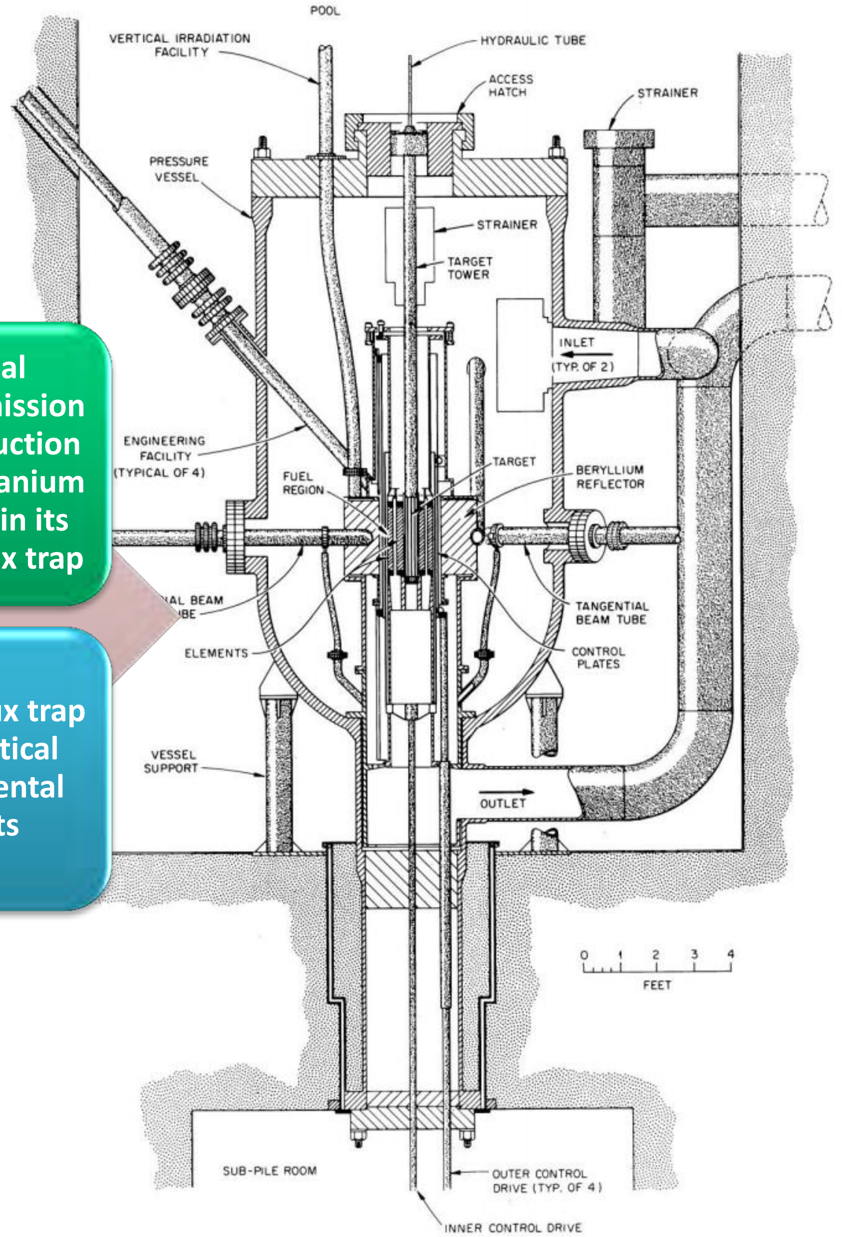
HFIR is a Multi-Purpose High-Performance Research Reactor

Operated since 1966 with one of the world's highest thermal neutron fluxes

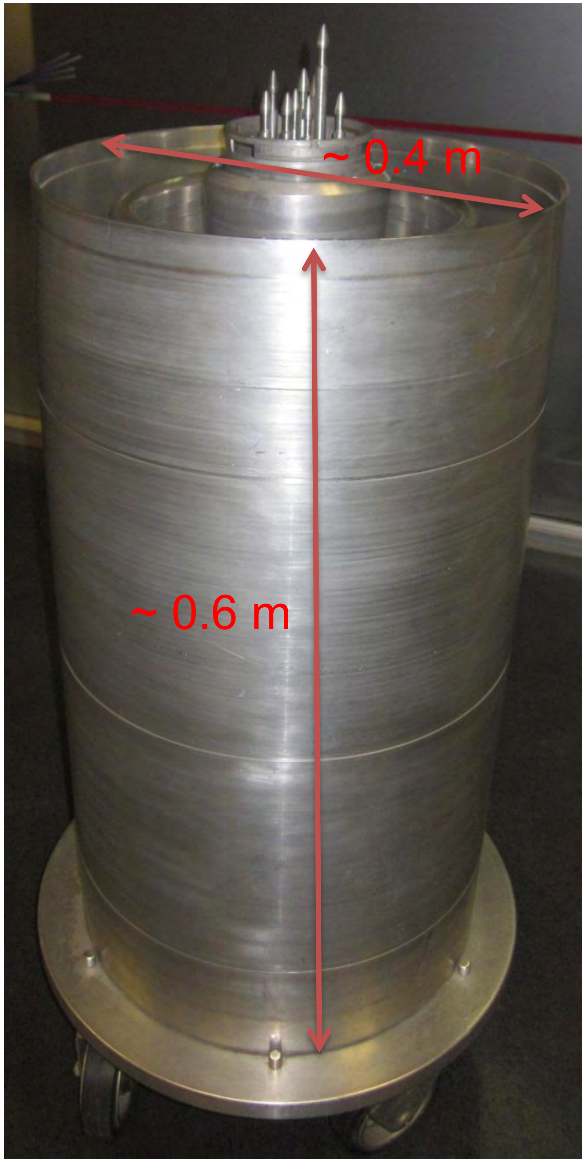
Original primary mission was production of transuranium isotopes in its central flux trap

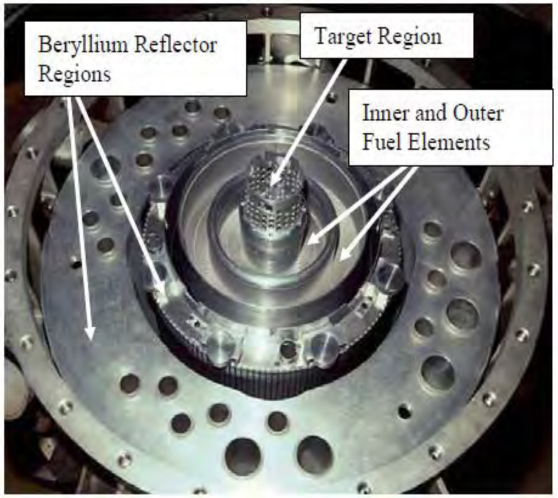
Pressurized light water cooled and moderated

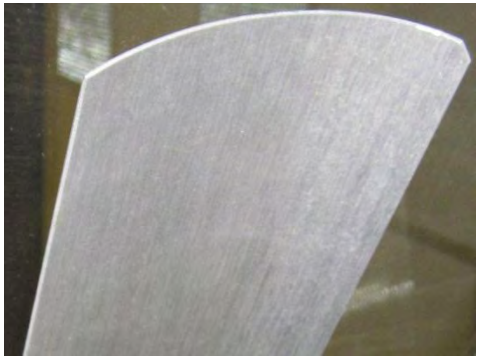
Central flux trap with vertical experimental targets

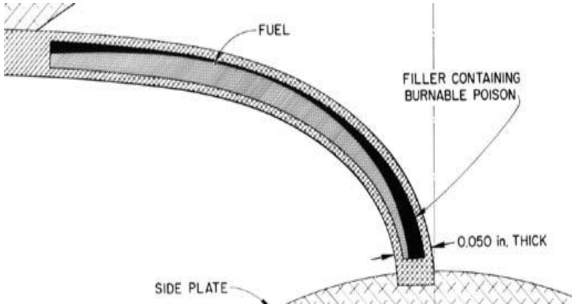


The HFIR Core



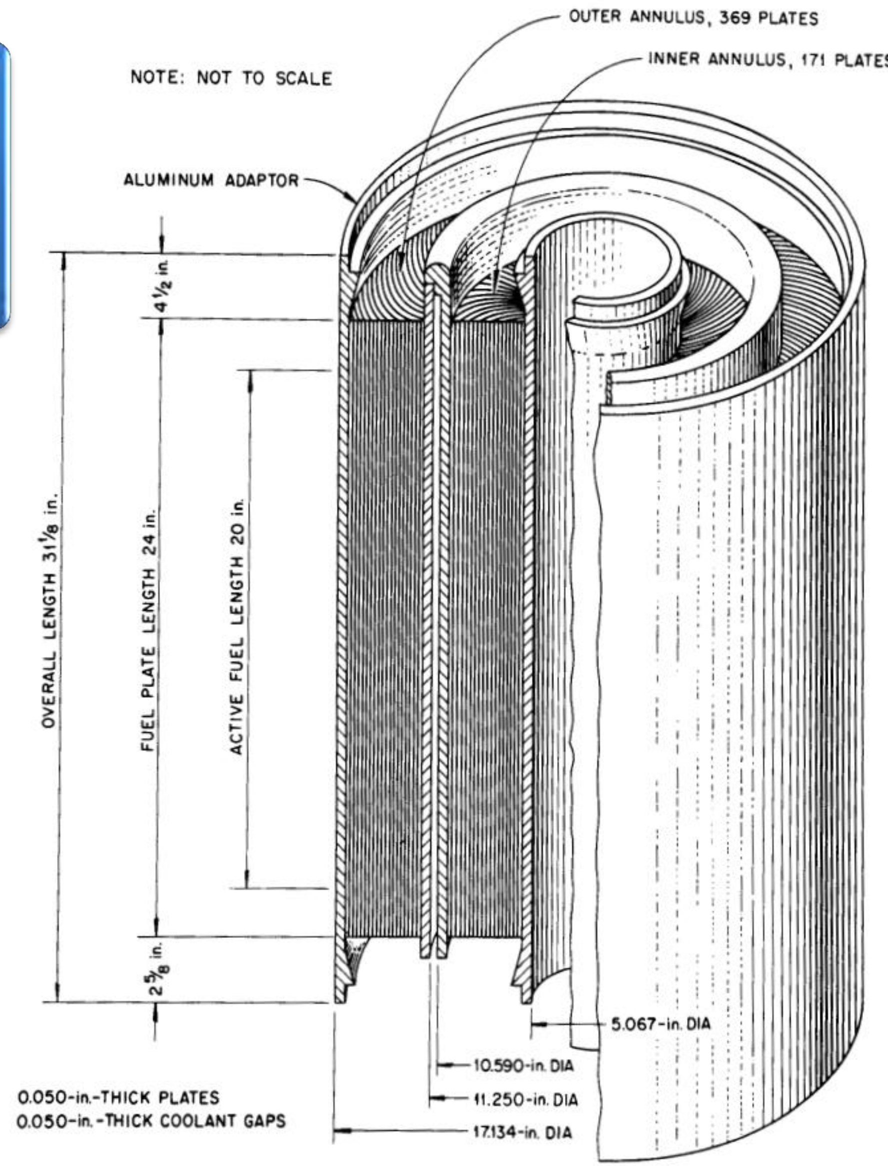






Physics of Interest for HFIR Safety Analyses

- Reactor Physics
- Turbulent Flows
- Conjugate Heat Transfer
- Thermal Structural Interaction (TSI)
- Fluid Structural Interaction (FSI)



- <u>Unique features for HFIR modeling</u>
  - Multi-physics problem
  - Non-uniform spatial heat source distribution inside the fuel plates (fuel, mixture, clad, radial and axial variation)
  - Nonlinear material property variation (~f(T))
  - Very narrow flow channels
    - High aspect ratio = H/t = 24 inch/0.05 inch = 480
  - Desired high level of accuracy and fidelity because of impacts on nuclear safety

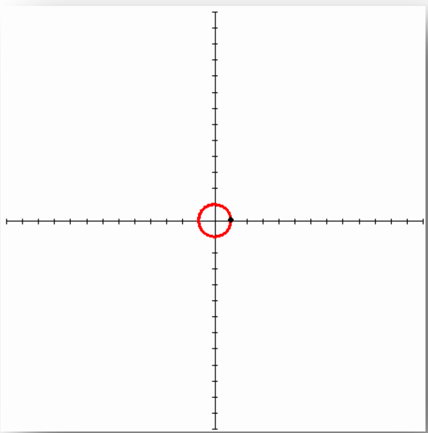
HFIR Single Fuel Plate 3D Model uses an Assembly of Parts to Create the Geometry

$$x(s) = R_{b_i}\left[\sin(s) - s\cdot\cos(s)\right],$$
$$y(s) = R_{b_i}\left[\cos(s) + s\cdot\sin(s)\right], \quad \text{where}$$
$$\theta_{\min} \le s \le \theta_{\max},$$

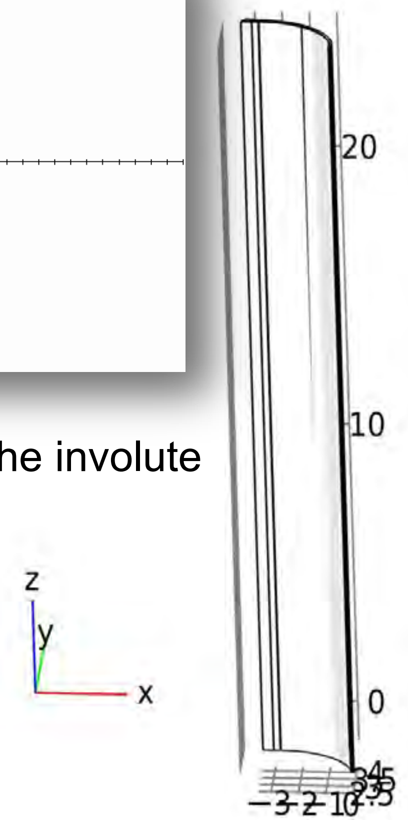
R_{b_i} = base radius of the involute, and

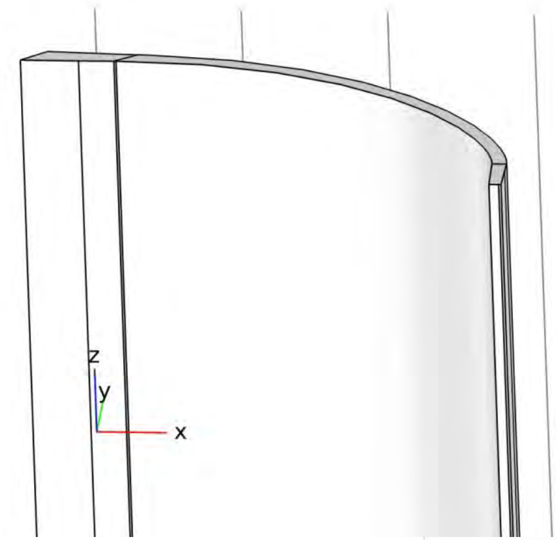
$\theta_{\min}$ = angle for the starting point of the involute, and

$\theta_{\max}$ = angle for the end point of the involute.

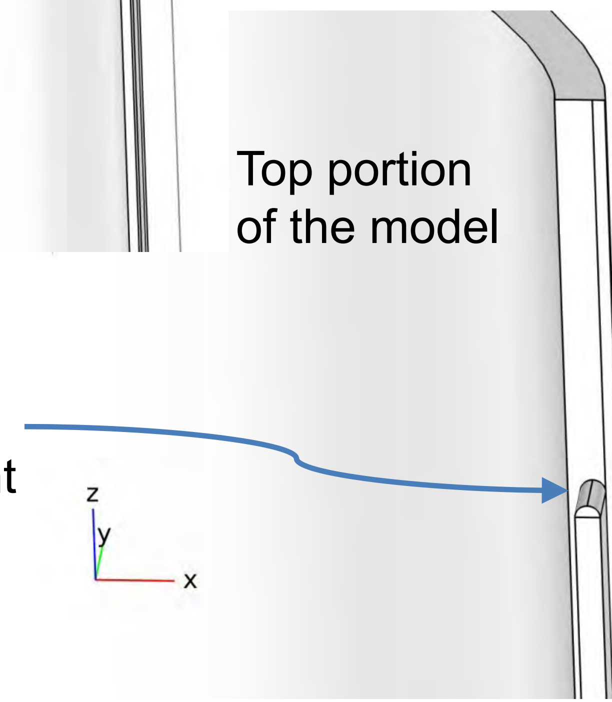


Equation of the involute of a circle



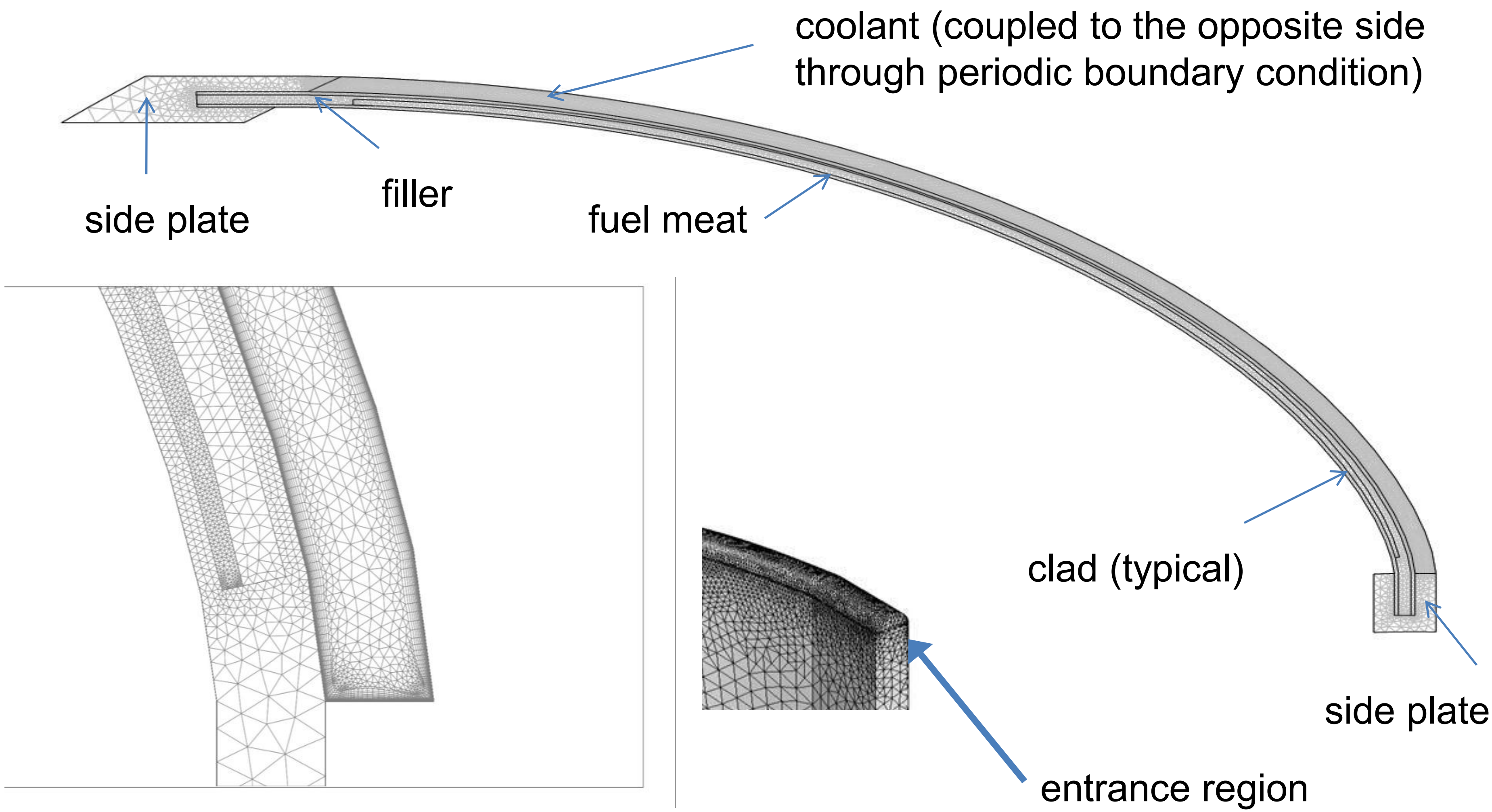


Top portion of the model

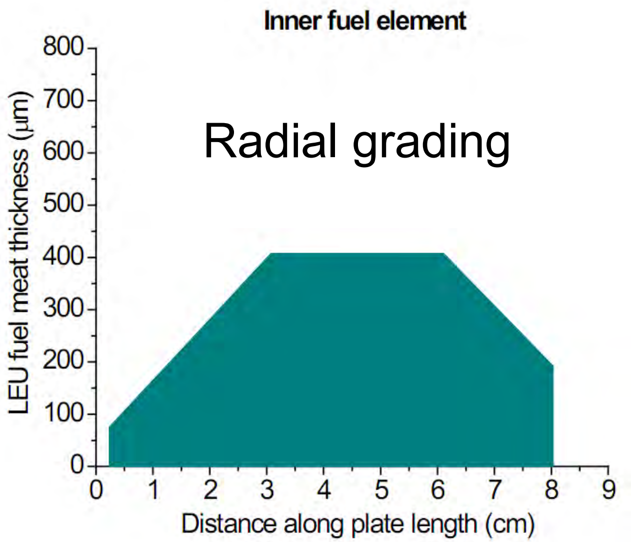


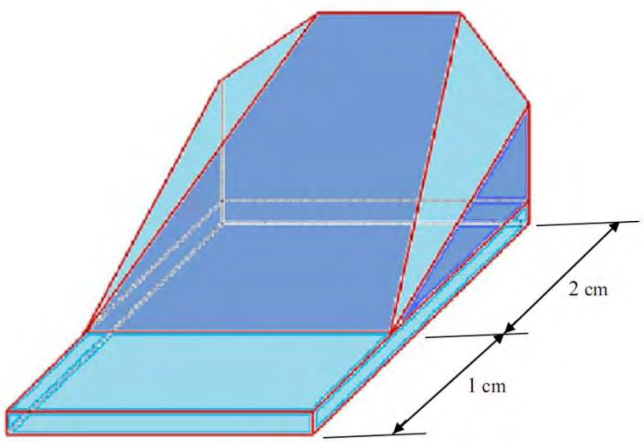
Side plate removed to expose coolant adjacent to the fuel plate

3D Meshing starts with a 2D Working Plane of the Involute Plate to be Extruded in the Axial Direction

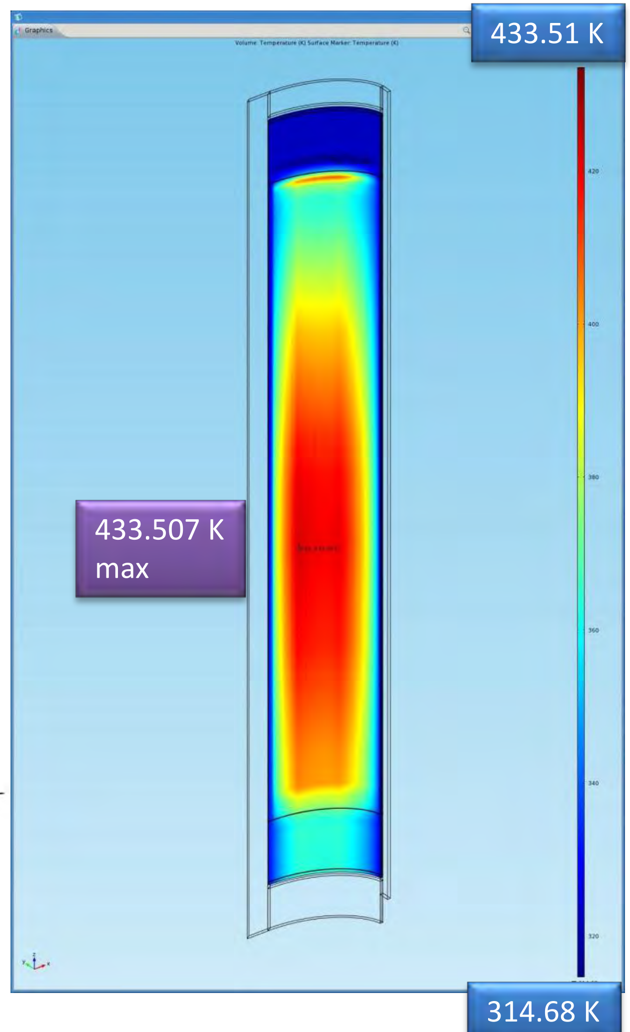


Coarse-Mesh SS Temperature Distributions for Proposed Designs of LEU Fuel for HFIR

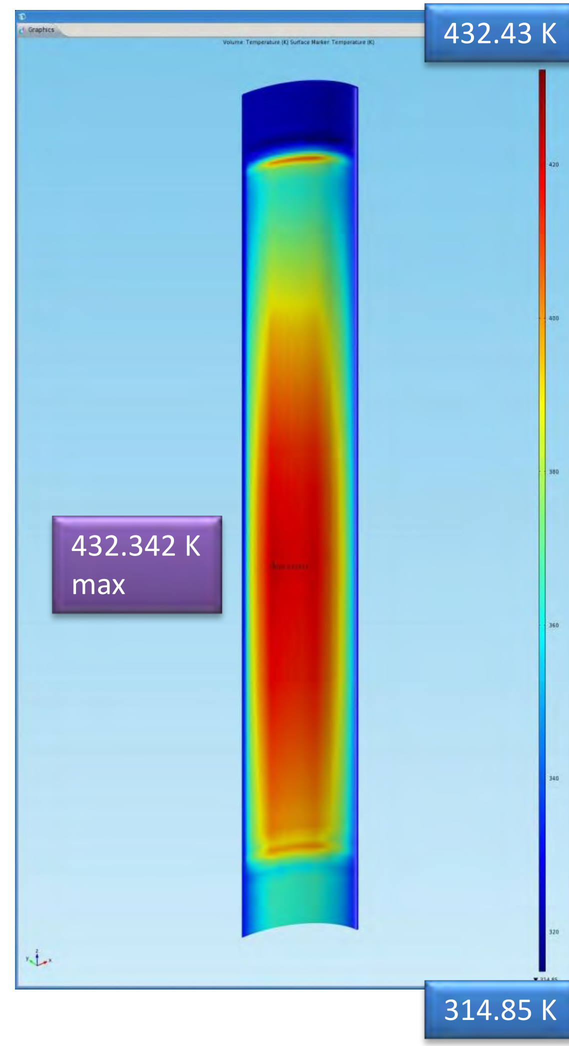




Axial grading (bottom of the fuel)

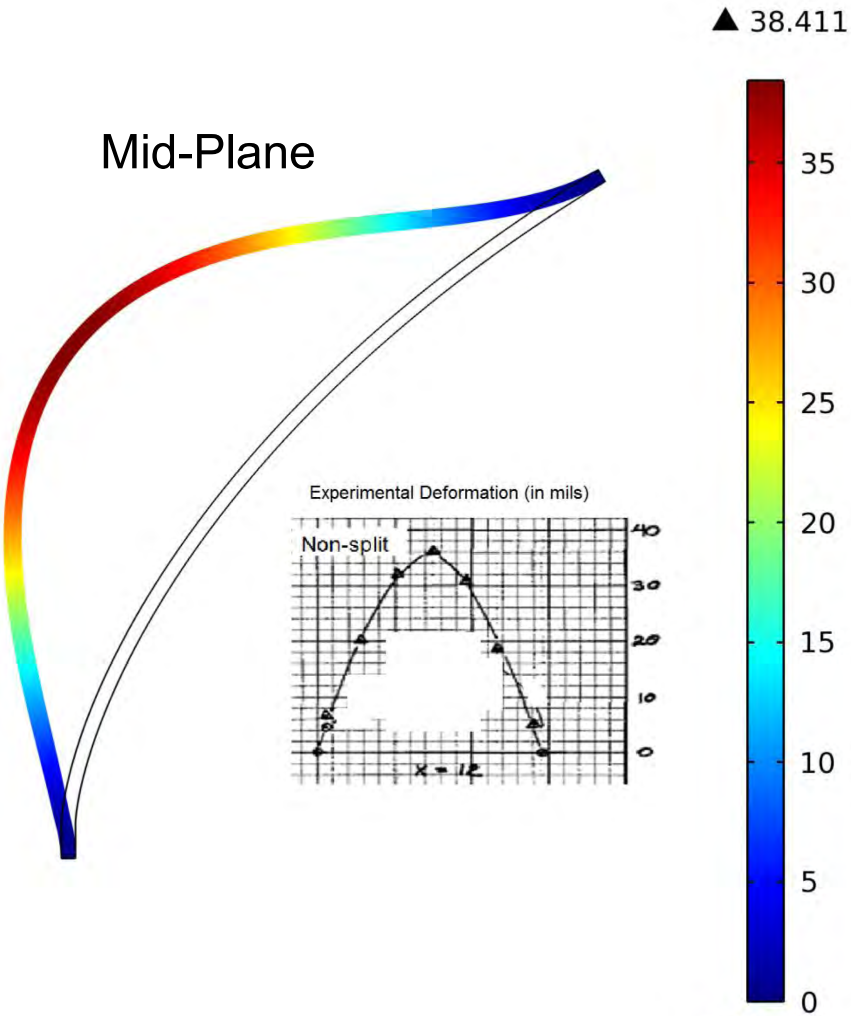


Axially Contoured

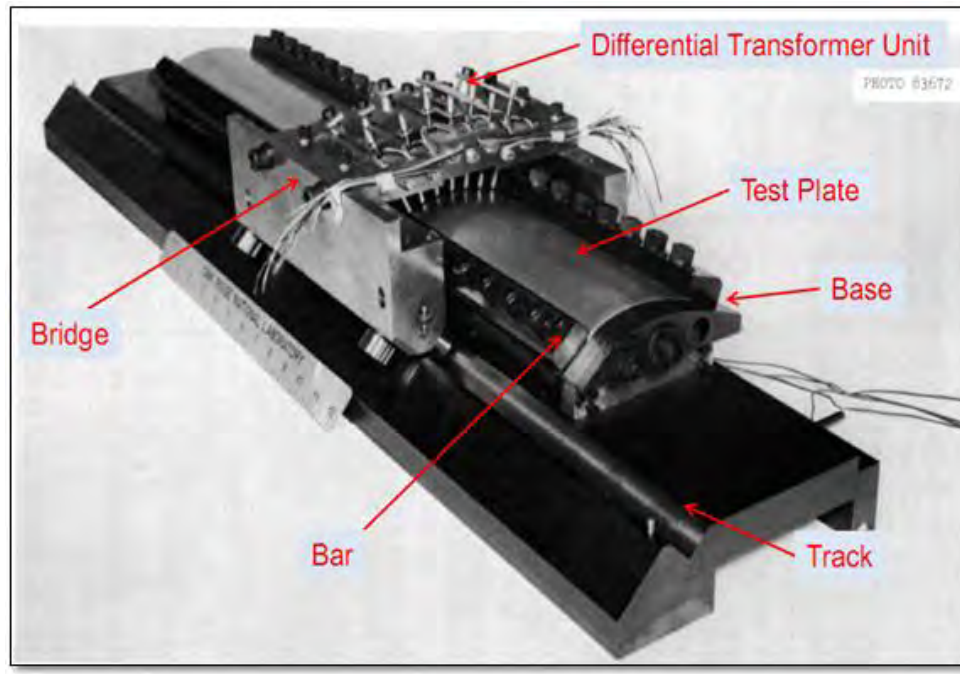


No Axial Contour

Thermal Expansion Simulation Results Agree Well with the Past Experiments

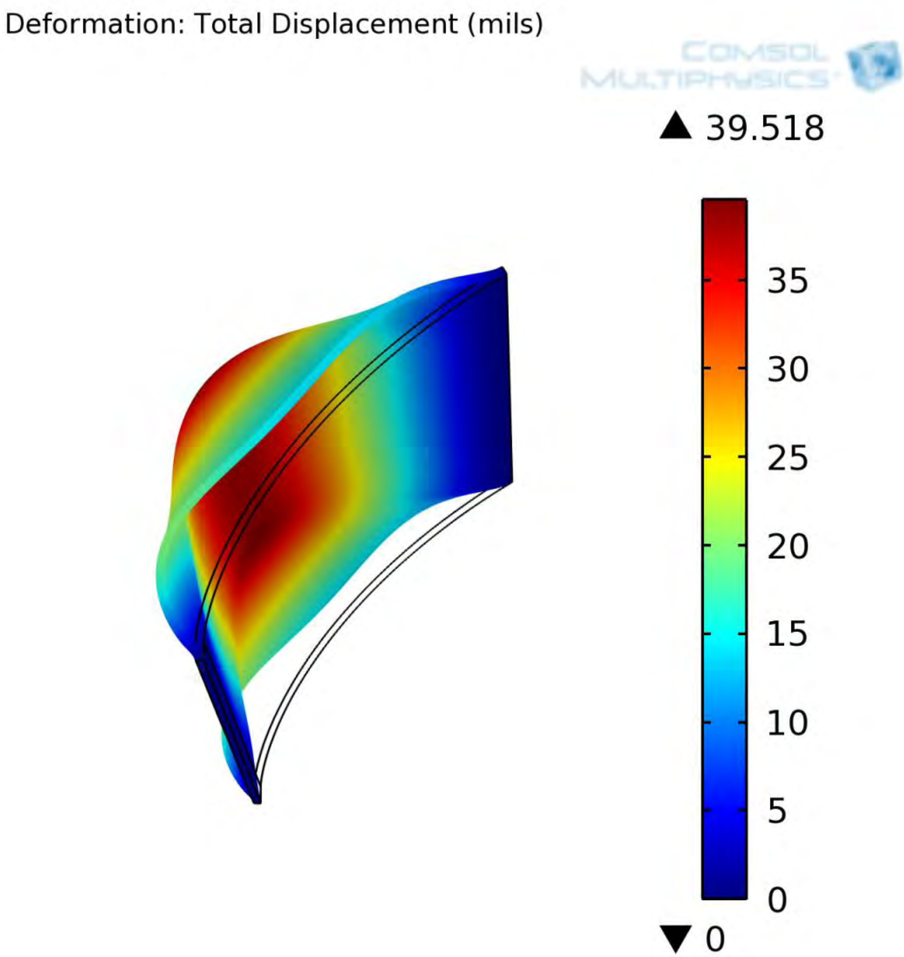


Test plate is heated from 80 °F to 400 °F in an oven to measure its thermally induced deflections.

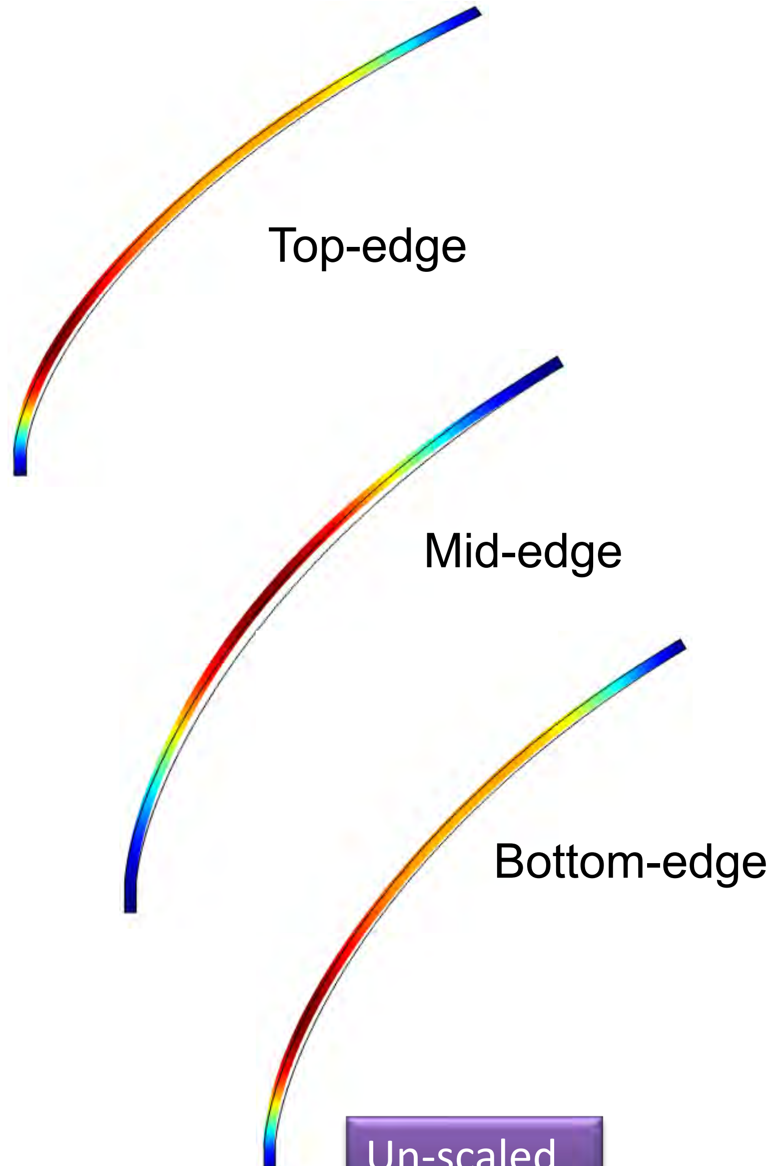


Simulated profile and maximum mid-plane deformation (= 38.4 mils) agree well with the experimental data (= 37 mils).

Thermally-induced Plate Deformations

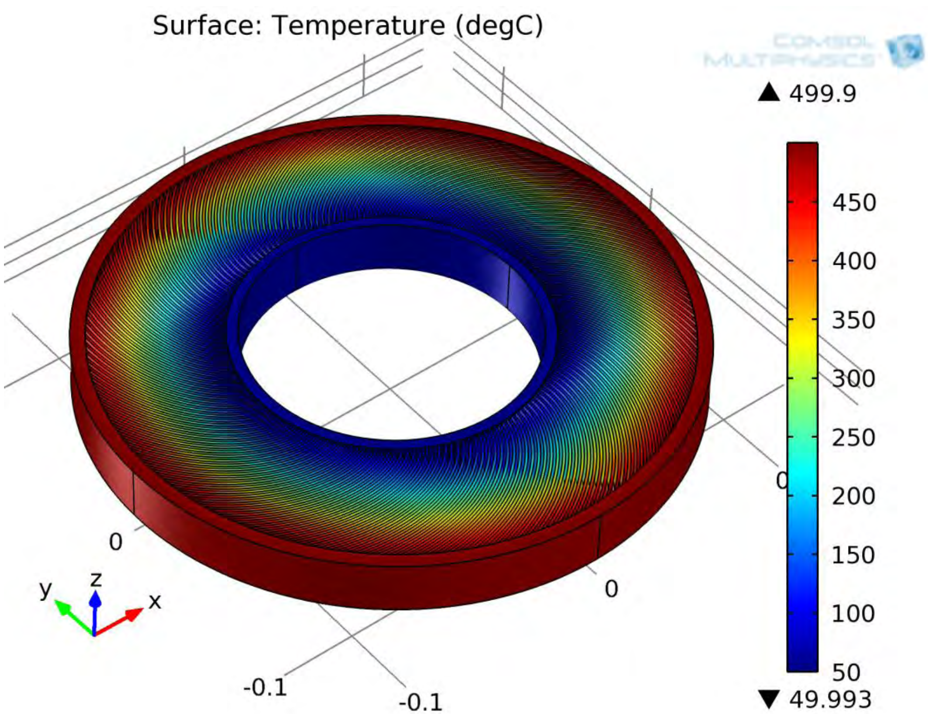


20x scaled

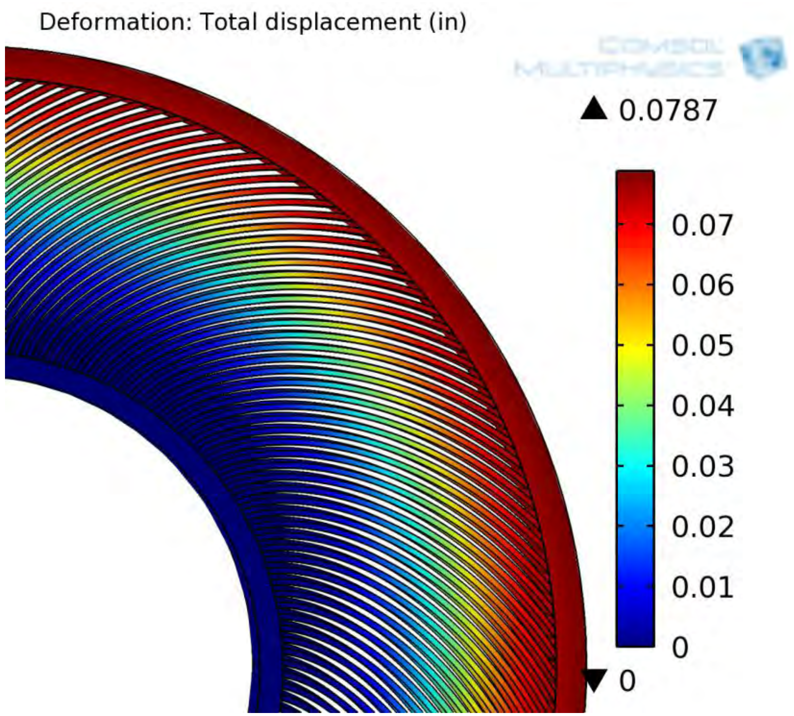


Un-scaled

Efforts have just started for full-core model developments



Steady state temperature distribution for the chosen heat conduction problem

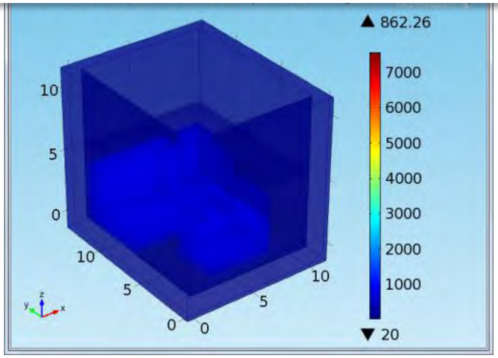


Steady state deformations due to thermal Expansion of the plates (in inches)

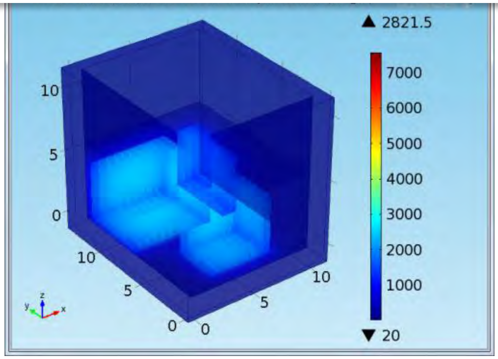
Steady state heat conduction in a 1-in cross-section of the HFIR's inner core geometry. Hypothetical constant temperature boundary conditions of 50 °C and 500 °C are assumed at the inner and outer side plates respectively for model verifications.

COMSOL's increasing visibility at ORNL

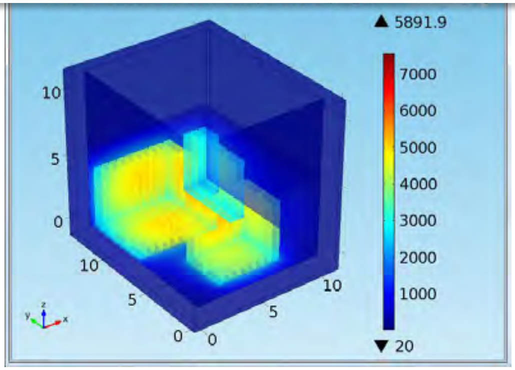
What would have happened if Fukushima's Spent Fuel Pool # 4 was entombed with Sand?



@ 4 days

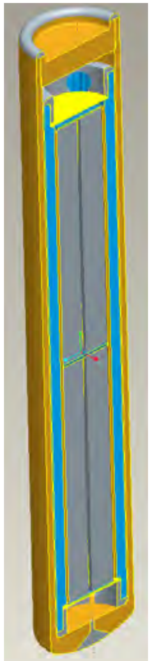


@ 16 days

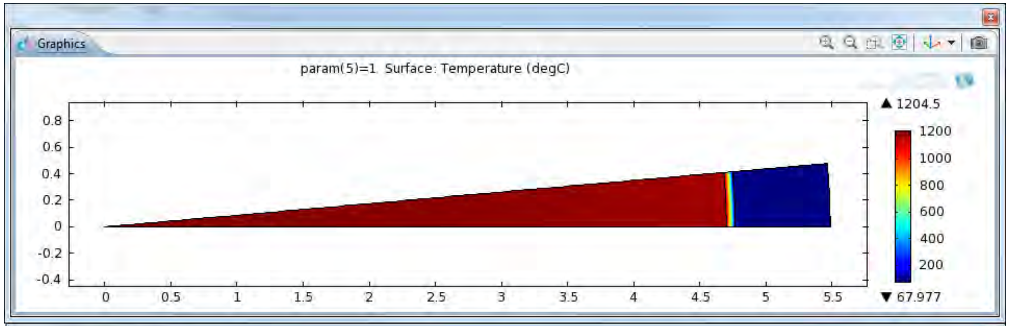


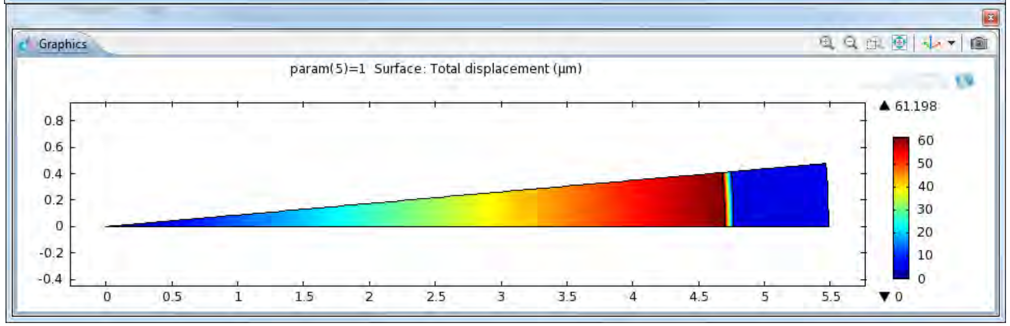
@ 50 days

Irradiation Engineering @ORNL

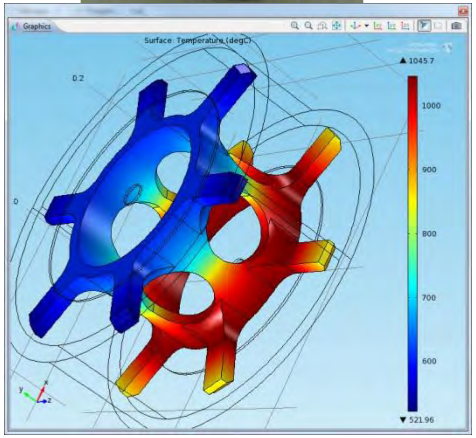


Capsule





Spacer



Conclusions and Current Status

- The HFIR LEU fuel conversion study is an ongoing project with advances being made in developing 3D modeling & simulation capabilities by adapting COMSOL as a baseline software.
- COMSOL is providing a modern simulation environment for the design of proposed LEU fuel, and analysis of present HEU fuel.
- COMSOL's unique capabilities to customize the models based on user-defined equations and in coupling multiple physics is very useful in detailed analyses, and in estimating nuclear safety margins.
- Parallel COMSOL computations are being performed on a 128-core cluster, and capabilities will soon be tested and utilized on some of the larger ORNL clusters.

Thank you for your attention.

Questions?

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